XI. Ecoregion Approach

In 1993, the Division began looking for a way to establish reasonable water quality expectations for different areas of the state. The existing approach of statewide criteria did not reflect Tennessee's diverse geography that ranged from the eastern mountains to the western plains. A method was needed for comparing the existing conditions found in a stream to the natural or reference condition in relatively unimpaired streams. The reference data needed to be from similar geographic areas to avoid inappropriate comparisons. It was important that the chosen approach provide scientific, practical, and defensible background data for the different parts of the state.

> An ecoregion is a relatively homogeneous area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, and other ecologically relevant variables.

In the 1980's, EPA developed a geographical framework called the ecoregion approach. In this approach, the United States is delineated into 76 different Level III ecoregions based on a similarity in climate, landform, soil, natural vegetation, hydrology and other ecologically relevant variables. Tennessee is divided into eight of these regions. The ecoregion approach seemed a reasonable way for the Division to determine regionally specific information for use in criteria development and refinement. In 1993, the Division initiated the ecoregion project to begin this process.

The ecoregion project was completed in four stages as outlined below. Details of the first three stages of the project can be found in *Tennessee Ecoregion Project 1994-1999* (Arnwine et. al., 2000). Details of the criteria proposals in stage four are presented in the referenced documents.

1. Delineate Subecoregion Boundaries

The eight Level III ecoregions comprising Tennessee were too large and diverse to be used for the establishment of water quality goals. Therefore, it was necessary to refine and subdivide the ecoregions into smaller, less complex units. Beginning in 1993, the Division arranged for James Omernik and Glenn Griffith of EPA's Corvalis Laboratory to subregionalize and update the ecoregions (Griffith et al., 1997).

Experts in many disciplines including aquatic biologists, ecologists, foresters, chemists, geographers, engineers, professors and regulatory personnel from 27 state and federal agencies as well as universities and private organizations were involved in this process. Maps containing information on bedrock and surface geology, soils, hydrology, physiography, topography, precipitation, land use and vegetation were reviewed. The result was the sub-delineation of Tennessee's eight (Level III) ecoregions into 25 (Level IV) ecological subregions (Table 11and Figure 20).

2. Reference Stream Selection

Reference sites were chosen to represent the best attainable conditions for all streams with similar characteristics in each of the 25 subregions. Reference condition represented a set of expectations for physical habitat, general water quality and the health of biological communities in the absence of human disturbance and pollution. Selection criteria for reference sites included minimal impairment and representativeness. Streams that did not flow across subregions were targeted so the distinctive characteristics of each subregion could be identified.

> A reference stream is a least impacted yet representative waterbody within an ecoregion that can be monitored to establish a baseline to which other waters can be compared. Reference streams are not necessarily pristine or undisturbed by humans.

Before monitoring began, 353 streams were evaluated as potential reference sites. Experienced Division staff used chemical and benthic macroinvertebrate samples as well as habitat assessments to trim the candidate streams down to a workable list. By the end of the study 98 reference streams were established. This represented between two and eight reference streams in each subregion.

3. Intensive Monitoring of Reference Streams

From 1996 to 1999, the reference sites were monitored quarterly for chemicals and bacteria. Chemical sampling generally included the parameters historically sampled by the Division in its long-term ambient monitoring network. Macroinvertebrate samples and habitat assessments were conducted biannually in spring and fall. Since 1999, the reference streams have been monitored in accordance with the watershed cycle (each stream is visited every five years).

4. Development of Regionally-based Water Quality Criteria

The data generated by reference stream monitoring has been used to develop proposals for standardized interpretation of existing narrative criteria. Summaries of these studies can be found under Chapter XII, special projects. Details of each project are presented in the referenced documents.

a. Nutrient Criteria (Denton et al., 2001)

b. Biological Criteria (Arnwine and Denton, 2001)

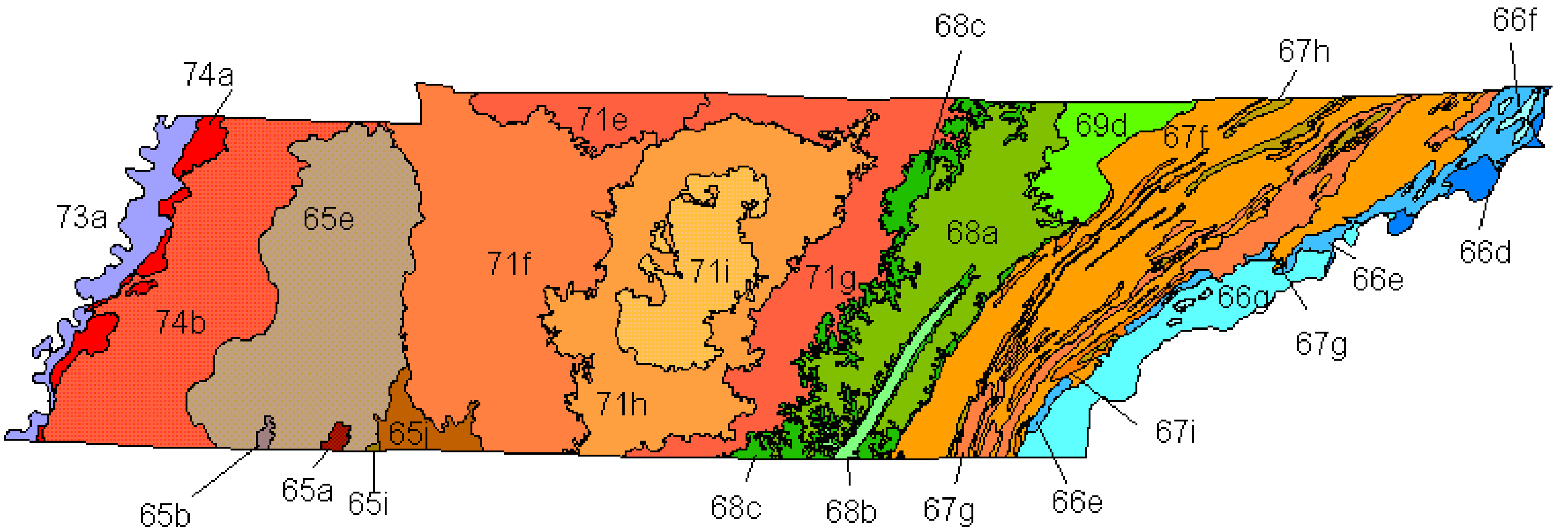
c. Habitat Guidelines (Arnwine and Denton, 2001)

During this triennial review year, other criteria are also being compared to the reference database to help refine water quality goals where appropriate. A proposal to regionalize pH criteria has been developed (Arnwine and Denton, 2002). Review of the dissolved oxygen data has indicated that the current standard may also need to be adjusted.

Table 11: Ecoregions of Tennessee

Ecoregion (Level III)	%State	Subecoregion (Level IV)	%State
65 - Southeastern Plains	12.1%	65a - Blackland Prairie	0.1%
		65b - Flatwood/Alluvial Prairie Margins	0.08%
		65e - Southeastern Plains and Hills	10.9%
		65i - Fall Line Hills	0.02%
		65j - Transition Hills	1.0%
66 - *Blue Ridge Mountains	6.0%	66d - Southern Igneous Ridges and Mountains	0.6%
		66e - Southern Sedimentary Ridges	1.9%
		66f - Limestone Valleys and Coves	0.3%
		66g - Southern Metasedimentary Mountains	3.2%
67 – Ridge and Valley	18.2%	67f - Southern Limestone Dolomite Valleys and Low Rolling Hills	12.6%
		67g - Southern Shale Valleys	3.4%
		67h - Southern Sandstone Ridges	0.8%
		67i - Southern Dissected Ridges and Knobs	1.4%
68 - Southwestern Appalachians	11.4%	68a - Cumberland Plateau	7.6%
		68b - Sequatchie Valley	0.6%
		68c - Plateau Escarpment	3.3%
69 – *Central Appalachians	2.1%	69d - Cumberland Mountains	2.1%
71 - Interior Plateau	37.4%	71e - Western Pennyroyal Karst	2.0%
		71f - Western Highland Rim	13.9%
		71g - Eastern Highland Rim	6.9%
		71h - Outer Nashville Basin	10.5%
		71i - Inner Nashville Basin	4.0%
73 - *Mississippi Alluvial Plain	2.0%	73a - Northern Mississippi Alluvial Plain	2.0%
74 - Mississippi Valley Loess Plains	10.7%	74a - Bluff Hills	1.1%
		74b - Loess Plains	9.6%

*Delineation of ecoregions in KY, NC, and GA may result in additional subregions in this ecoregion.



65a Blackland Prairie
65b Flatwoods/Alluvial Prairie Margins
65e Southeastern Plains and Hills
65i Fall Line Hills
65j Transition Hills
66d Southern Igneous Ridges and Mtns
66e Southern Sedimentary Ridges
66f Limestone Valleys and Coves
66g Southern Metasedimentary Mountains
67f Southern Limestone/Dolomite Valleys and Low Rolling Hills
67g Southern Shale Valleys
67h Southern Sandstone Ridges
67i Southern Dissected Ridges & Knobs
68a Cumberland Plateau
68b Sequatchie Valley
68c Plateau Escarpment
69d Cumberland Mountains
71e Western Pennyroyal Karst
71f Western Highland Rim
71g Eastern Highland Rim
71h Outer Nashville Basin
71i Inner Nashville Basin
73a Northern Mississippi Alluvial Plain
74a Bluff Hills
74b Loess Plains

Figure 20: Level IV Ecoregions of Tennessee

XII. Special Projects

A major goal of the Division is to establish measurable safe levels of pollutants to replace current narrative criteria and to refine existing statewide numeric criteria to reflect natural regional differences. The ecoregion reference stream monitoring project (Chapter XI) gathered sufficient information to establish reasonable numeric water quality expectations for the current narrative nutrient, biological and habitat criteria. Reference stream data were also used to develop a proposal for refining the existing statewide pH criterion to reflect regional differences. The ecoregion project also prompted additional studies into the suitability of the current dissolved oxygen criterion.

A. Proposed Nutrient Criterion

A significant number of impacted stream miles in Tennessee are due to elevated nutrient levels. There are currently no specific narrative criteria for nutrients. Nutrients are assessed under the more generic “free from” statements in the toxicity section of the fish and aquatic life criteria and the “aesthetic” section of the recreational criteria. Thus, before any stream could be assessed as impacted by nutrients, the existence of a problem had to be established. The purpose of this study was to develop subecoregion specific interpretations of the narrative nutrient criteria for total phosphorus and nitrate+nitrite for the 2002 triennial review of water quality standards.

Reference stream data obtained during the ecoregion reference project (Chapter XI) were used to determine naturally occurring nutrient levels in each ecological subregion across the state. Standard statistical methods were used to identify differences in nutrient concentrations between subregions. Where differences were significant, the adoption of subregion-based criteria was considered appropriate due to improved accuracy. However, where differences between subregions were not significant, regional data were aggregated so that the resulting criteria could apply to streams that crossed subregions.

Data from across the state were used to field test potential criteria levels. Reference data at both the 75th and 90th percentile were evaluated. Every subregion tested supported the use of the 90th percentile as less restrictive nutrient criteria that did not penalize streams supporting a healthy benthic community.

The relationship between biological stream health and nutrient concentration was tested using reference stream data and the results of a 2000 survey of randomly selected monitoring stations in the Inner Nashville Basin (Section E). Very few associations were identified except for a very weak correlation between nutrients and EPT genera (aquatic insects in the generally pollution sensitive orders Ephemeroptera, Plecoptera and Trichoptera). Multiple regression analyses indicated it was the interaction of several pollutants, including nutrients, which led to a loss of biological integrity. Additional samples were collected at these stations and are pending analysis.

Stronger correlations were seen in four other subregions. These data were not random, but pooled from existing databases. The data seem to indicate that nutrients and biological integrity are most directly linked when other factors, such as habitat quality, are not limited.

It is likely that nutrients are indirectly associated with biological health. Under the right conditions increased nutrient levels generally result in algal blooms. High levels of algae affect dissolved oxygen as well as render habitat unavailable for colonization by macroinvertebrates. This in turn causes stress to the benthic population. Additional information as well as proposed criteria levels for both total phosphorus and nitrate+nitrite can be found in the document *Development of Regionally-Based Interpretations of Tennessee's Narrative Nutrient Criterion* (Denton et. al., 2001).

In July 2002, additional federal nutrient criteria development funds were used to conduct algal field surveys and nutrient sampling for comparison to diurnal dissolved oxygen patterns in both reference quality and impaired streams in 16 ecological subregions. Algal and nutrient data generated during this study will be used to test a correlation between algal abundance, nutrient levels and diurnal dissolved oxygen patterns. This will in turn help Tennessee refine proposed nutrient criteria and attempt to establish baseline algal biomass. Findings of this study will be published in 2003.

Increased nutrient levels can result in algae blooms which affect dissolved oxygen levels and stress the aquatic life. (Photo provided by Annie Goodhue, Nashville EAC.)

B. Proposed Biological Integrity Criterion

Biological criteria or "biocriteria" are used to define expected biological conditions. The health of the benthic community is an important indicator of disturbances in the watershed. Biological communities are good indicators of actual conditions because they inhabit the stream continuously and are subject to the various chemical and physical influences that occur over time. Loss of biological integrity is often the result of environmental impacts such as habitat destruction, siltation, flow-alteration, organic enrichment, reduced dissolved oxygen, pH fluctuations and elevated metals.

Tennessee's current biological criterion is narrative. It specifies that streams shall not be modified to the extent that the aquatic life is substantially decreased or adversely affected. However, the terms substantially and adversely are open to interpretation. Additionally, the existing narrative criterion requires that the condition of the biological communities be measured by the use of metrics. However, it does not specify what metrics are to be used. Since different metrics measure different aspects of the biological community and have different levels of sensitivity to pollution, application of the existing criterion relies heavily on which metrics are selected and individual interpretations of stream health. A more standardized measurement calibrated to specific bioregions is needed to effectively assess biological integrity in a consistent and fair manner.

The purpose of this study was to develop guidance for interpretation of biological data based on regional reference data collected as part of the ecoregion project (Chapter XI). Reference biological data were collected by single habitat semi-quantitative samples of benthic macroinvertebrates.

Benthic macroinvertebrates are animals that live on the bottom of streams that do not have a backbone and are large enough to see with the naked eye. Examples include crayfish, mayflies and clams. The advantages of using macroinvertebrates as water quality indicators include their sensitivity to various types of chemical pollution, dependency on stable habitat, limited mobility, high diversity and vital position near the bottom of the food chain.

The single habitat semi-quantitative sample method was used to collect the animals because it is easily standardized and has been found to yield consistent results. Two different sample methods (riffle kicks or bank jabs) were used depending on the most prevalent stream type in each ecoregion.

Biologists using kick nets collect benthic macroinvertebrates from riffle areas. (Photo provided by Jonathon Burr, Knoxville EAC.)

After analysis of the reference data, a biological index was developed to measure the health of the macroinvertebrate community. This index was based on seven biometrics representing different aspects of the biological population. Multiple biometrics are calculated when assessing biological integrity since it is common for one attribute of the aquatic community to change in response to impact while others remain unchanged.

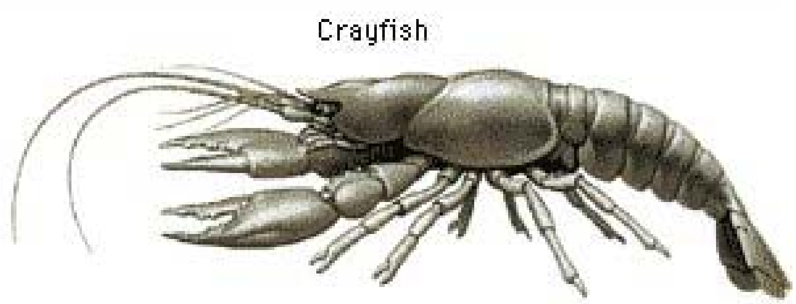
Ecological subregions were grouped into bioregions based on similarity of the reference macroinvertebrate populations. Fifteen bioregions, each with distinct macroinvertebrate communities, were defined in Tennessee. The seven biometrics were used to evaluate each bioregion (except in the Mississippi Alluvial Plain where only five of the biometrics proved applicable). Different expectations for each biometric were determined based on a quadrisection of the 10th or 90th percentile of reference data for each bioregion. The biometric values in each bioregion were than combined into a biocriterion index for each region. Test sites scoring at or above this level would be considered supportive of a healthy biological community. More details regarding this study can be found in *Development of Regionally-Based Numeric Interpretations of Tennessee's Narrative Biological Integrity Criterion* (Arnwine and Denton, 2001).

C. Proposed Regionalization of pH Criteria

The purpose of this study was to develop regional pH criteria for wadeable streams and rivers based on reference data collected as part of the ecoregion project (Chapter XI). Tennessee's existing statewide pH criterion is 6.5 to 9.0 standard units. Reference stream data indicated this did not reflect background water quality conditions in many areas of the state and did not allow for obvious regional differences.

pH is a way of expressing both acidity and alkalinity. Common causes of acidity in Tennessee streams are resource extraction and construction activities. Alkalinity is generally a problem more common in lakes and reservoirs with the most common cause being eutrophication.

When streams become excessively acidic or alkaline, the change can adversely impact aquatic life. Macroinvertebrates with shells or hard exoskeletons, such as crayfish, are unable to molt in acidic conditions while fish may experience altered gill function. Fish and macroinvertebrates unable to tolerate the altered conditions decline while tolerant organisms increase due to a lack of competition for food and habitat. This results in an unhealthy biological community dominated by a few tolerant taxa.



One of the biggest concerns is that pH levels can increase the toxicity of other pollutants in the water. The pH of water determines the solubility and biological availability of heavy metals. Metals tend to be more toxic at lower pH because they are more soluble. Runoff from mines, agricultural, domestic and industrial areas may contain iron, aluminum, ammonia, mercury or other elements. The pH of the water determines the toxic effects, if any, of these substances.

Following statistical comparison of reference and test data, it was proposed that the statewide pH criterion be changed to 6.0-9.0 for wadeable streams in the majority of the state. Lower pH criteria were proposed for three regions that had naturally acidic systems (Cumberland Plateau, Transition Hills and Loess Plains).

Details of this project, including recommendations for adjustments to pH criteria based on regional data can be found in the *Development of Regionally-Based pH Criteria for Wadeable Streams*, (Arnwine and Denton, 2002).

D. Diurnal Dissolved Oxygen Study

The amount of dissolved oxygen (DO) present in the water is critical to aquatic life. Oxygen gets in the water by surface air diffusion, aeration from turbulence and the photosynthesis of aquatic plants and algae. Most fish and aquatic macroinvertebrates cannot obtain oxygen directly from the air and are dependent on oxygen dissolved in the water to survive.

Pollution tends to cause a decrease in stream oxygen concentrations. One of the main factors resulting in low dissolved oxygen is the buildup of organic wastes, which are anything that was once part of a living plant or animal including food, leaves, feces etc. Common sources of organic wastes entering streams include sewage, urban runoff, crop runoff, dairies, feed lots and industrial sources such as food processing plants. Indirect sources of organic wastes include fertilizers from urban and agricultural runoff that stimulate the growth of algae and aquatic plants. As the plants die, aerobic bacteria consume oxygen in the process of decomposition.

> Aquatic life is dependent on oxygen dissolved in water to survive. Pollution, such as organic wastes, can cause a decrease in stream oxygen concentrations.

Depletion of dissolved oxygen can cause major shifts in the kinds of aquatic organisms found in streams. Species that cannot tolerate low levels of dissolved oxygen such as trout, darters, mayflies and stoneflies are replaced by pollution tolerant organisms such as carp, green sunfish, midge larvae and aquatic worms.

The current fish and aquatic life protection criterion for dissolved oxygen (DO) has not been revised in many years. The criterion suggests that the minimum acceptable dissolved oxygen levels in any stream is 5 mg/l, but notes that DO can go as low as 3 mg/l. A review of dissolved oxygen data from ecoregion reference streams indicates that these criteria may be overly protective, particularly in the Mississippi Alluvial Plain where animals are adapted to the naturally low dissolved oxygen levels in the sluggish, organically-rich streams. On the other hand, the existing criteria may not be fully protective of fish and aquatic life in other regions, particularly mountainous areas of east Tennessee where natural aeration provided by cold water running over rocks keeps dissolved oxygen levels well over 5 mg/l.

One problem with existing reference data is that they were all collected during daylight hours when dissolved oxygen levels are at their highest level. Oxygen is produced during photosynthesis and consumed during respiration and decomposition. Because it requires light, photosynthesis occurs only during daylight hours. At night photosynthesis cannot counterbalance the loss of oxygen through respiration and decomposition so DO concentrations steadily decline.

Preliminary investigations conducted by the Division have demonstrated a definite fluctuation of Dissolved Oxygen within a 24-hour period in response to temperature and the photosynthesis cycle (Figure 21). Based on this information, regional criteria factoring into account variations in natural patterns in dissolved oxygen levels seems more appropriate than the current approach.

In July 2002, the Division initiated an intensive diurnal dissolved oxygen study funded by a 104(b)(3) grant to resolve this issue. Dissolved oxygen probes capable of continually recording dissolved oxygen levels were placed in 72 reference and 72 test sites in 16 ecological subregions. The probes were left for one week at each site to record the diurnal dissolved oxygen patterns occurring in the stream. Monitoring was completed in October, 2002, and the data will be used to provide a basis for possible adjustments to dissolved oxygen criteria to better reflect diurnal fluctuations within each subregion.

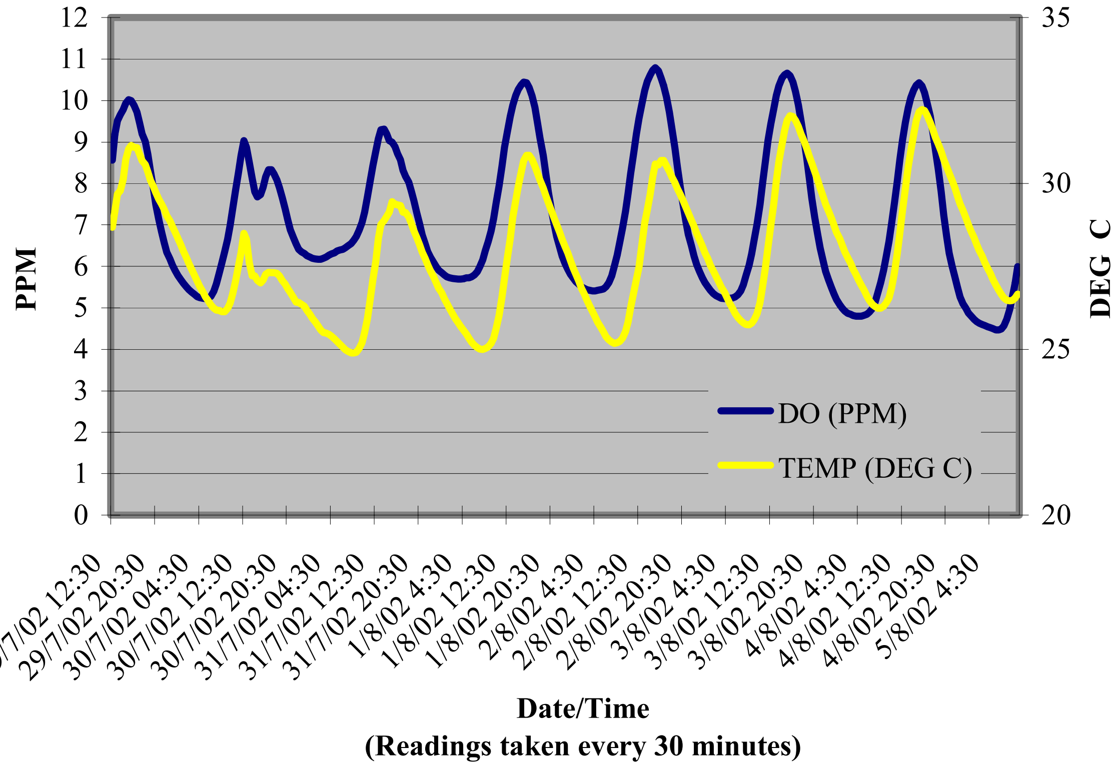


Figure 21: Typical Diurnal Dissolved Oxygen Patterns in the Outer Nashville Basin (71h). (Stream monitored for one week in August 2002).

E. 71i Probabilistic Monitoring Project

In 2000, the Division used Federal 104(b)(3) funding to conduct a probabilistic monitoring study to assess water quality in ecological subregion 71i (Inner Nashville Basin). Probabilistic monitoring is the random selection of sites to conduct water quality investigations to get an idea of overall water quality in a given area. This study consisted of monitoring 50 sites in six watersheds for chemical, biological and bacteriological conditions (TDEC, 2000).

> Thin soil, karst limestone, intermittent surface streams, and cedar glades characterize the 71i Inner Nashville Basin.

Level IV sub-ecoregion 71i, the Inner Nashville Basin, is located east of Nashville between Old Hickory Lake and the Duck River. This is one of the fastest growing areas of the state including parts of Franklin, Lebanon and Murfreesboro. The Inner Nashville Basin is one of five sub-ecoregions of the Interior Plateau. Six major watersheds are located in this subregion: Old Hickory and Cheatham Reservoirs (both impoundments of the Cumberland River), Stones River, Harpeth River, and Upper and Lower Duck River.

Cedar Creek, a typical Inner Nashville Basin (71i) stream. This photo illustrates one of the common water quality problems in Tennessee, direct access by cattle to streams. (Photo provided by Debbie Arnwine, Planning and Standards.)

Streams in this area are typically low gradient with bedrock substrate although a few streams have cobble substrate with riffle areas. Many streams do not have year round flow. Even in natural conditions, habitat for aquatic life is poor.

Chemical, physical, and biological samples were collected at the 50 test sites and two reference sites between January 2000 and June 2001 (Figure 22). The information obtained from this study was compared to ecoregion reference site data and the existing historical monitoring sites.

Objectives of the 71i Probabilistic Monitoring Project are as follows:

1. Characterize water quality at each of the probabilistic monitoring stations. Document violations of water quality standards and determine the degree of support of designated uses. Determine likely sources of pollutants in impacted segments.

2. Extrapolate probabilistic data to the entire sub-ecoregion, providing data for the development of the statewide assessment report. (However, it should be noted that extrapolated data should not be used for 303(d) listing purposes, except for the specific sites monitored.)

3. Compare water quality assessment information extrapolated from probabilistic sampling to historical assessments within 71i to provide a sense of the accuracy of historical targeted monitoring efforts.

4. Determine if the Division's reference streams in ecoregion 71i were appropriately selected. If superior sites are identified through random sampling, the data from those sites could be substituted for existing ecoregion reference sites.

5. Develop assessment methodologies to distinguish naturally occurring environmental stresses in the Inner Nashville Basin from those caused by pollutants, land use and/or other outside factors.

6. Determine if a direct correlation between macroinvertebrate populations and nutrient levels can be measured in this subregion. Test proposed biological and nutrient criteria.

Findings of the first five objectives have already been published (Arnwine and Denton, 2002). All samples have been analyzed except for the May/June 2001 macroinvertebrate samples. Results have been included in the watershed assessment portion of this report. The final data reduction and interpretation is scheduled to be published in 2003.

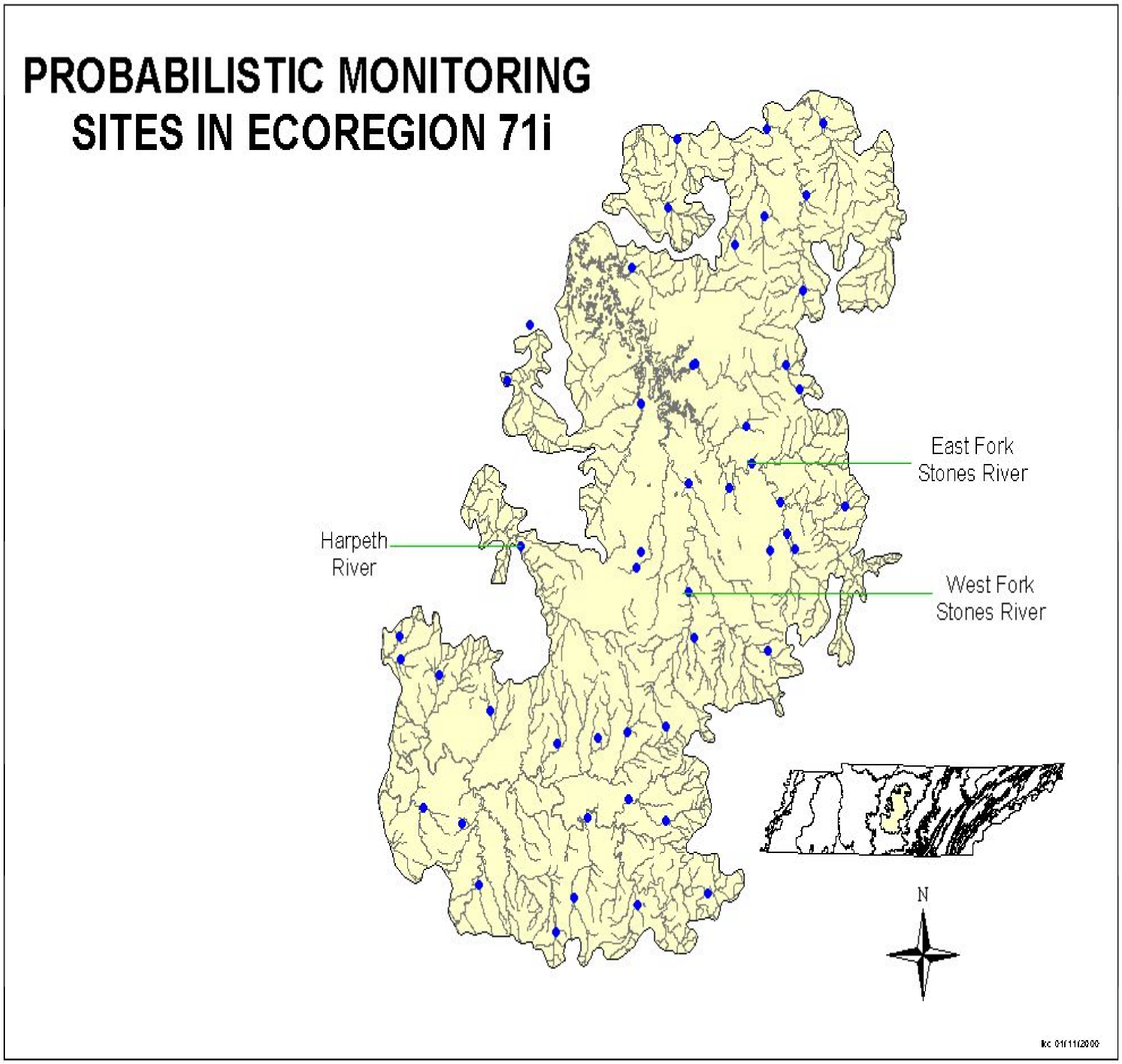


Figure 22: Probabilistic Monitoring Sites in Ecoregion 71i.